Sediment exports from French rivers

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Géosciences pour une Terre durable brgm

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Study framework

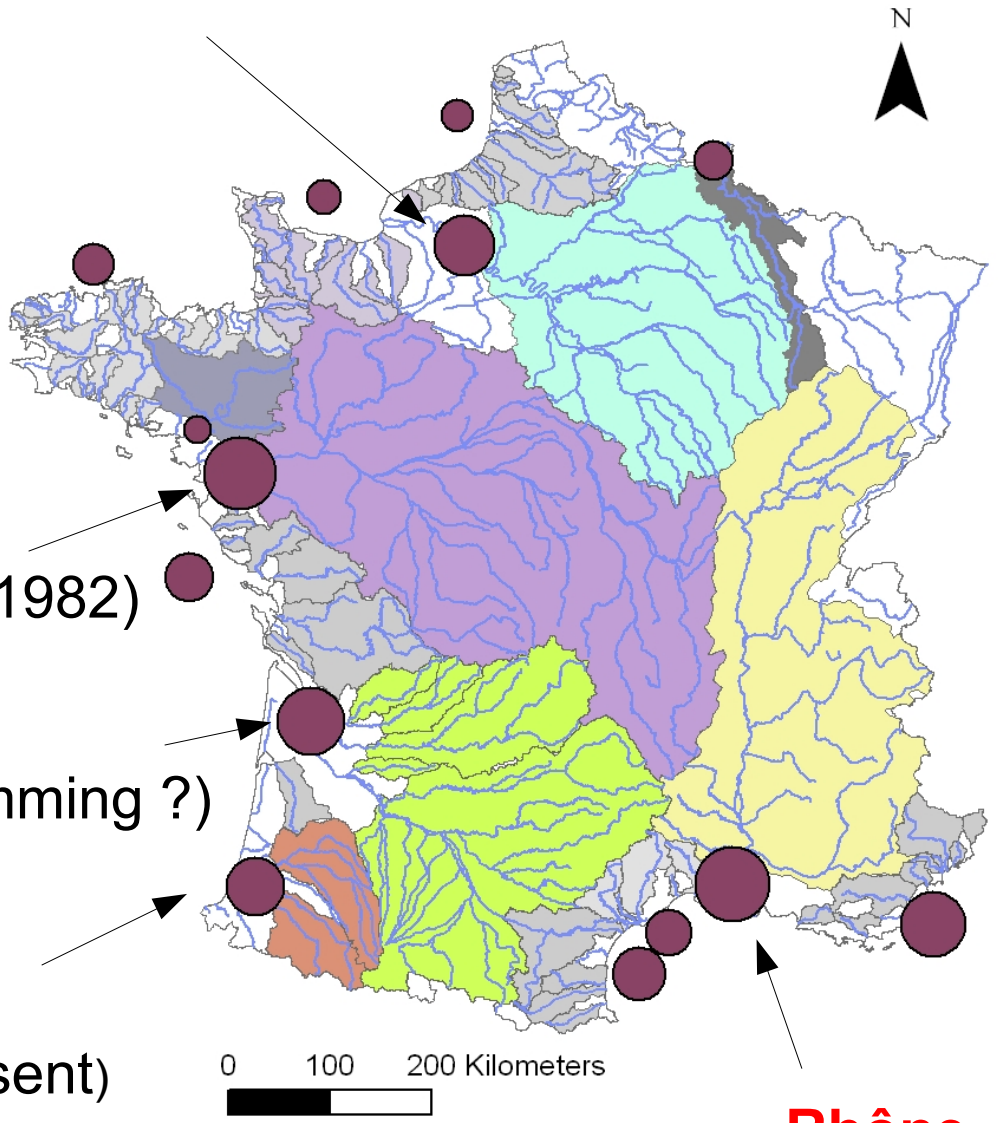
- Asses Sediment Delivery Ratio for French basins at various scales
- Map erosion sources that reach the catchment outlets.
- Tackle issues such as phosphorus inputs to rivers
  - Agricultural phosphorus is becoming the limiting factor for algal growth
  - Fallout derived contaminants such as PAH or metals
  - Pesticide runoff potential, although mostly dissolved
- Sediment Delivery Ratio (SDR) based on
  - SSY : Specific Sediment Yield (tons/km^2/y)
  - ER : Erosion rates at field scale

Part of PhD work by Magalie Delmas, defended on May 18th

Data sources for sediment fluxes ?

- Most papers who need sediment flux estimates refer to few compilations (global scale)
  - Milliman et al. (1995), LOICZ-IGBP, Meybeck and Ragu (1995), UNEP/GEMS/GLORI, FAO database
- A huge but non homogeneous work
  - Various data sources, estimation methods...
  - Present versus past (before damming) fluxes
  - Highly variables sampling periods and durations
- Sometimes local studies

Seine
3,5 Mt/y (??)
0.7 Mt/y (present)



Loire
12 Mt/y (FAO, 1981-1982)

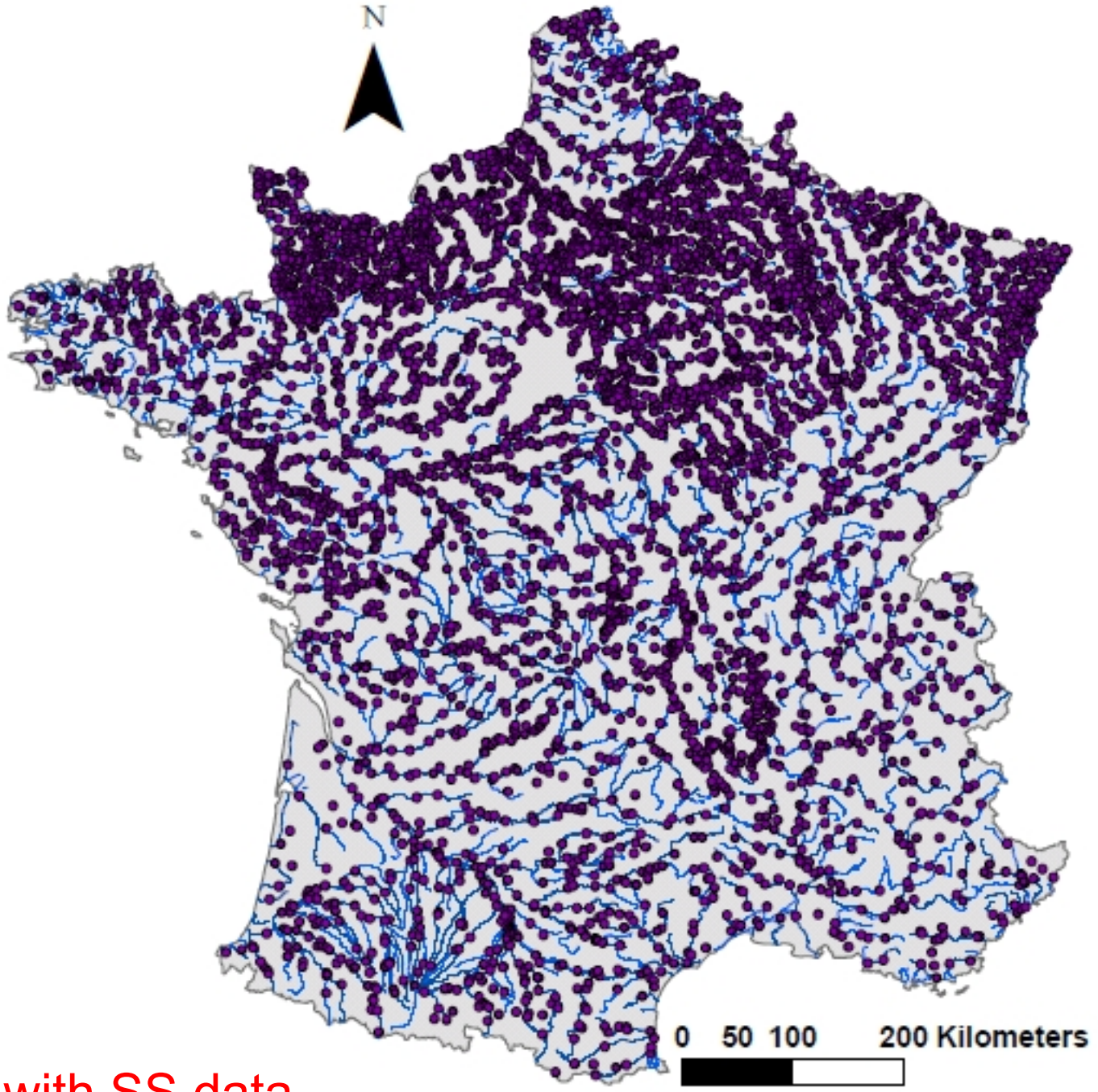
Garonne
4.5 Mt/y (before damming ?)
1.4 Mt/y 1974-1981

Adour
0.24 Mt/y (present)

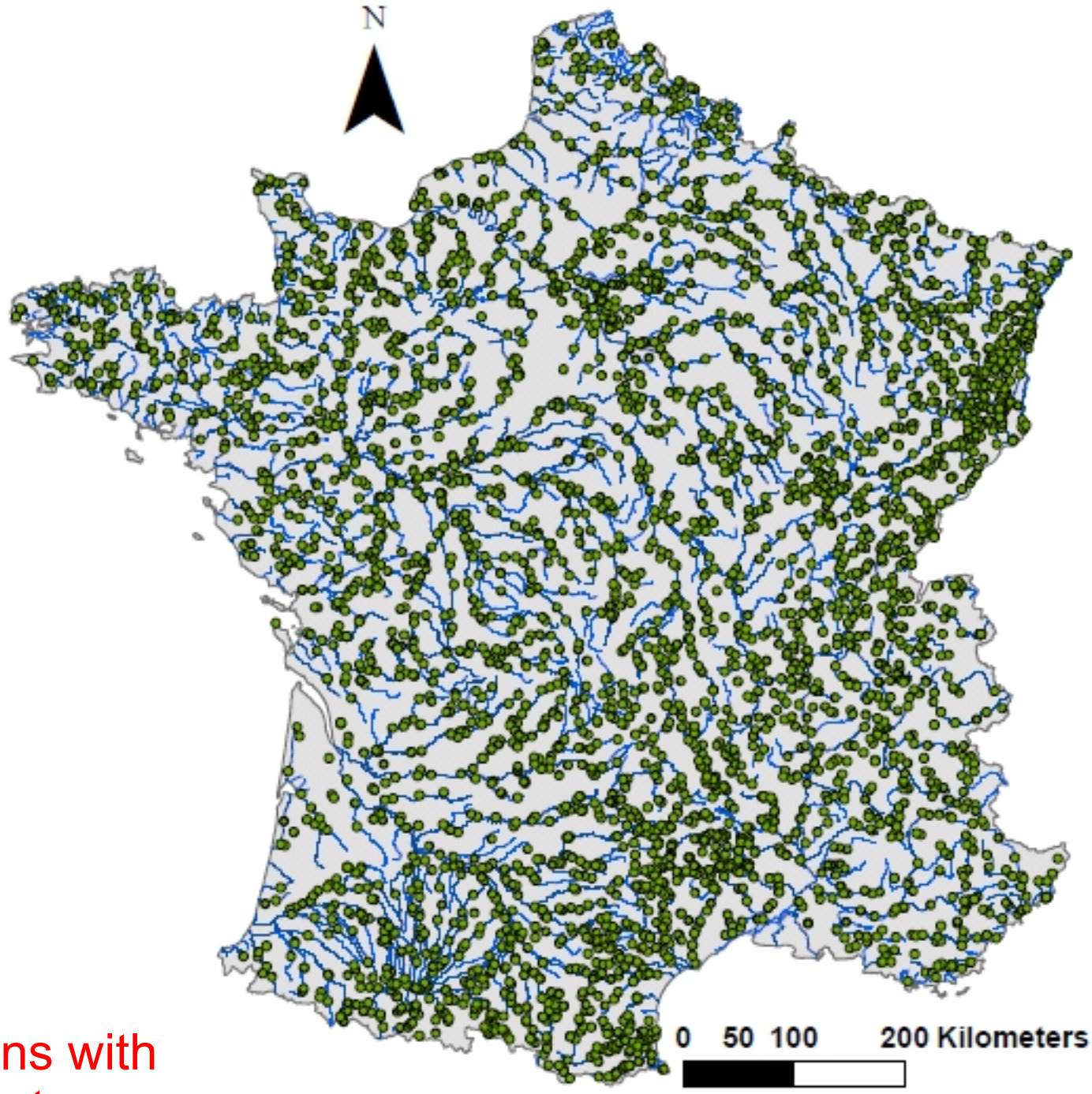
Rhône
31 Mt/y (before damming)
56 Mt/y (before damming)

Get our own sediment fluxes

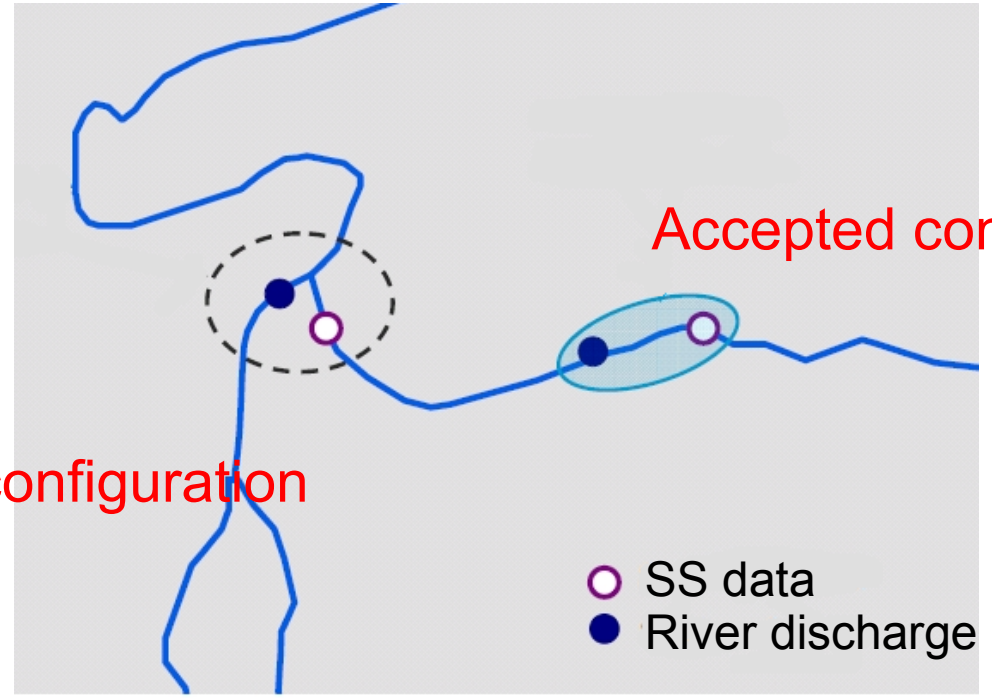
- Mean fluxes for 10 year periods (or more)
  - Yearly fluctuations up to a factor of 10 for “gentle” river Seine
  - Erosion rates also highly variable at the yearly scale
- Almost no high frequency monitoring data
  - Some monitoring at water intakes (legal)
  - Recent programs for the main French rivers (Rhône, Garonne system, Loire, Seine on-going)
    - Not yet available, except for Rhone
- National water quality survey
  - “once a month”



5579 stations with SS data
looks great !



3500 stations with
daily flow data



260 stations finally accepted,
with more than 10 years SS data
with well estimated catchments

Main problems

- Cross-section heterogeneity, poor (?) representativity
  - Specific surveys required, many times a year
  - Done on high frequency stations
  - No results for most stations
    - Problem must be left aside 
- Infrequent data
  - Determine acceptable strategies

Main methods to cope with missing data

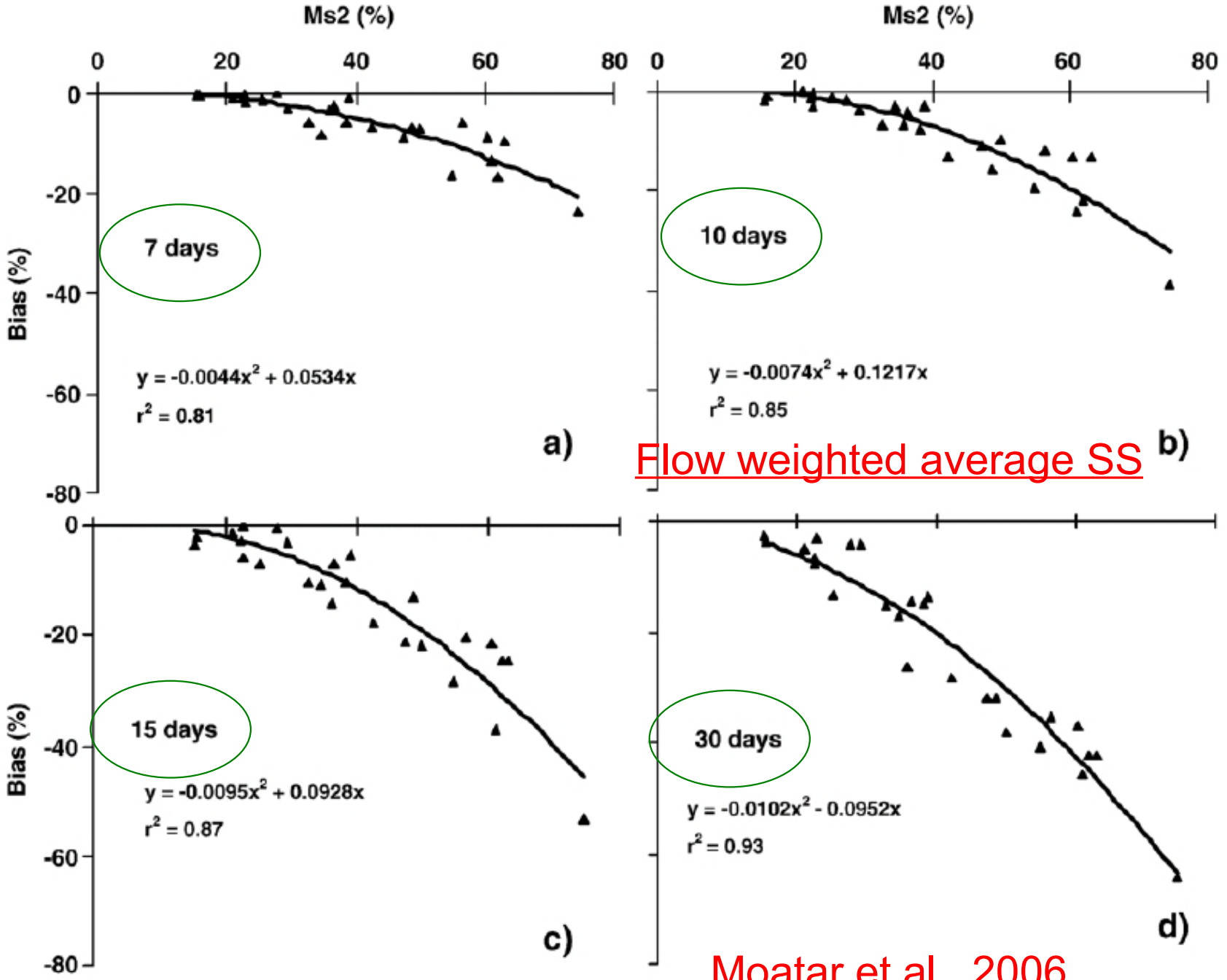
- A risky one :
  - Use sediment fluxes when SS data, and average
    - information on river flow is lost
- A better one :
  - Re- construct missing SS data and use all Q (river discharge) data
    - “flow weighted average” SS
    - reconstruct from rating curve : SS = f(Q,...) + ε(...)
- Evaluate methods by sub-sampling data sets
  - Using additional catchments (USGS !)

Several recent studies by French groups

- Coynel et al. 2004 (STOTEN)
  - Error on fluxes estimates, frequency, catchment size
- Moatar et al. 2006 (STOTEN)
  - Error on fluxes estimates, frequency, catchment size
- Sebastien Raymond PhD, 2011
  - Many methods tested on SS, major ions, nutrients. On-going publication

Fraction of yearly sediment flux occurring during 2% of time (1 week)

Average biais

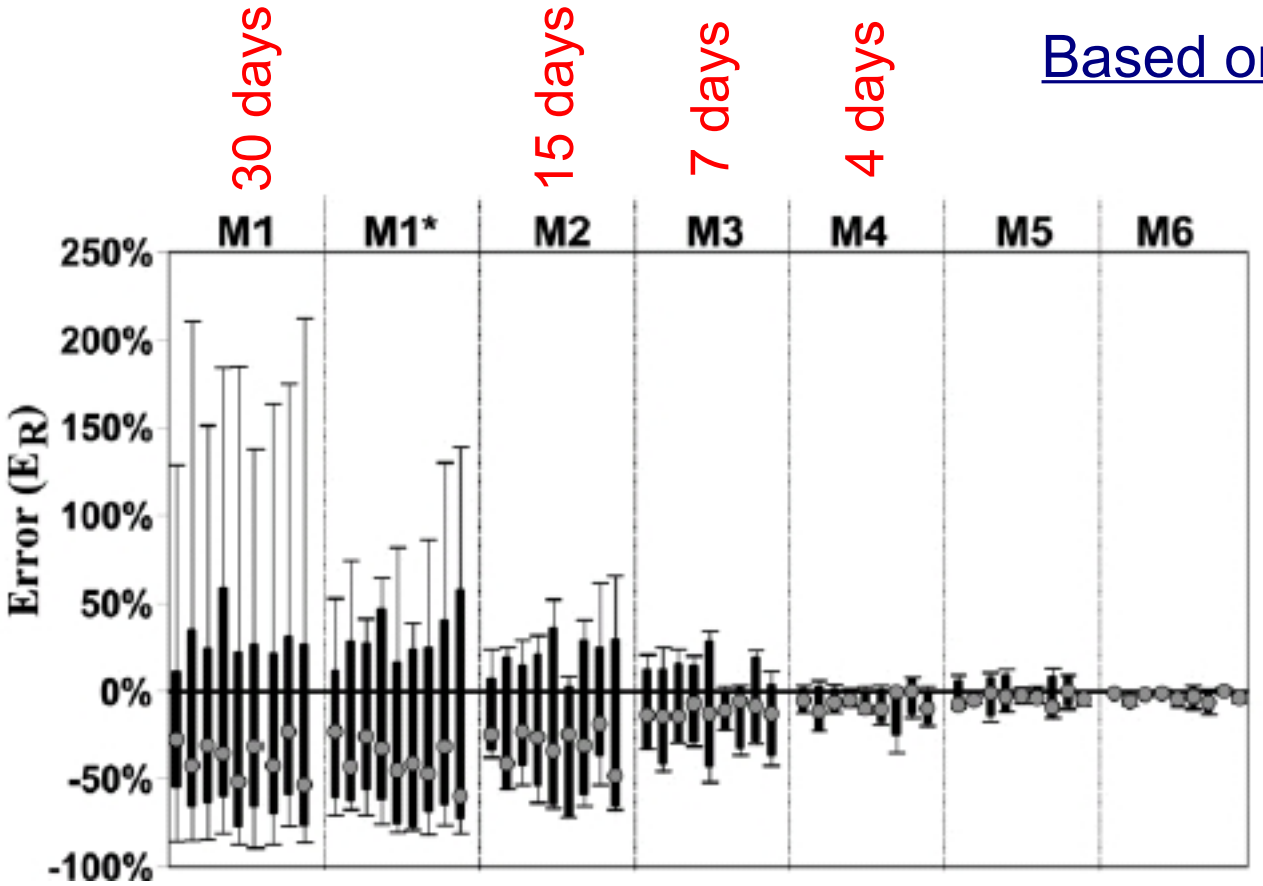


Flow weighted average SS

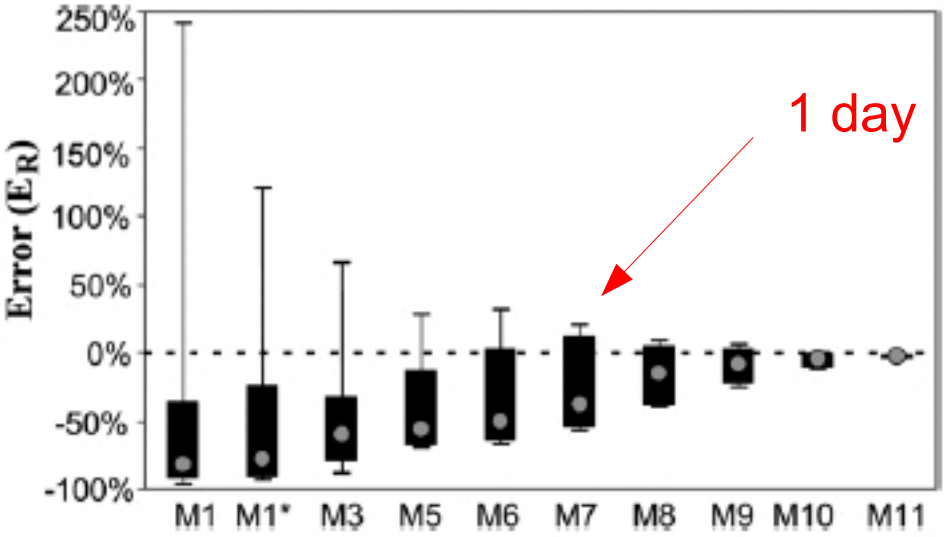
Moatar et al., 2006

Based on the « risky » method

Garonne : 53 000 km²



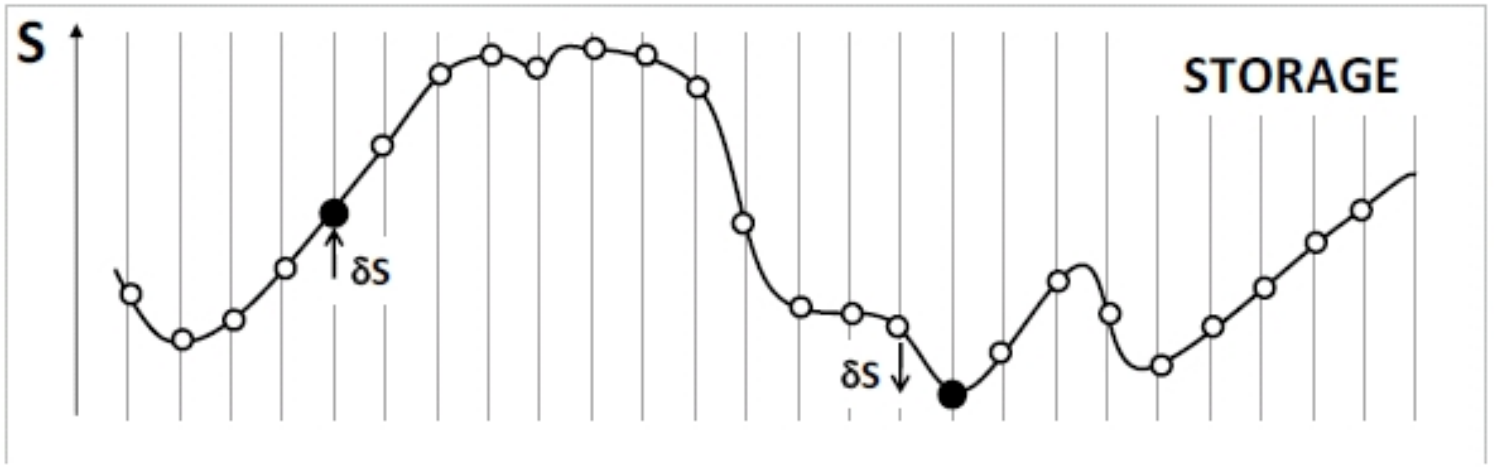
Nivelle : 165 km²



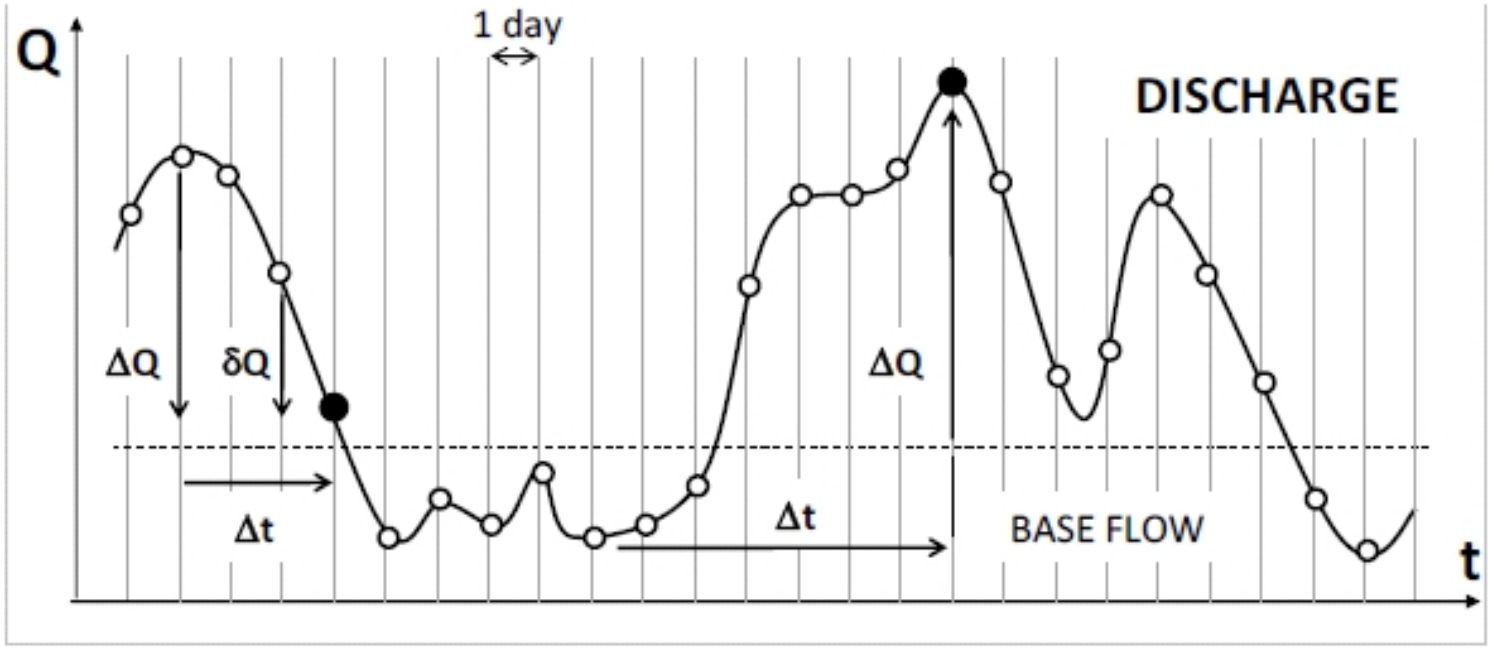
Coynel et al., 2004

"Improved" rating curve method (IRCA)

- Usual rating curve SS = $a.Q^b + \varepsilon(...)$
- IRCA : SS = $a.Q^b + c.\delta S + \varepsilon(...)$
  - Average value for low flow
- S is a stock index
  - Should be high (~1) when much erodible sediment is present
  - Should be low (~0) when no erodible sediment is present
- S as a function of Q
  - Different for rising flow or declining flow
- Tested on USGS database
  - 5% decrease of RMSE



a) Sediment Storage indicator presented as the S(t) chronicle

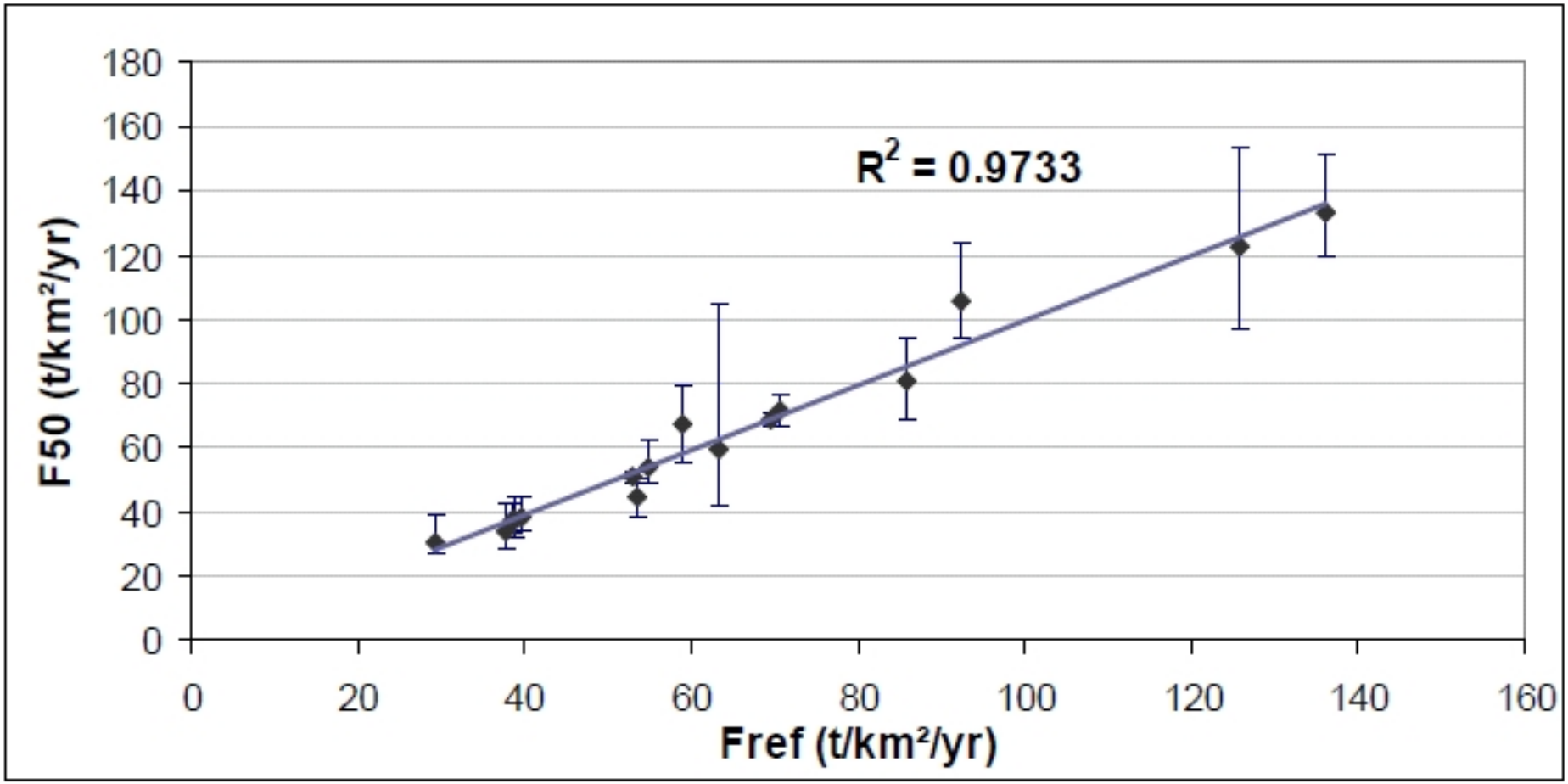


b) Discharge Q(t) chronicle used in fitting the C(Q) relations

$$S(t) = \exp(-Q_f \,.\, F / Q_0)$$

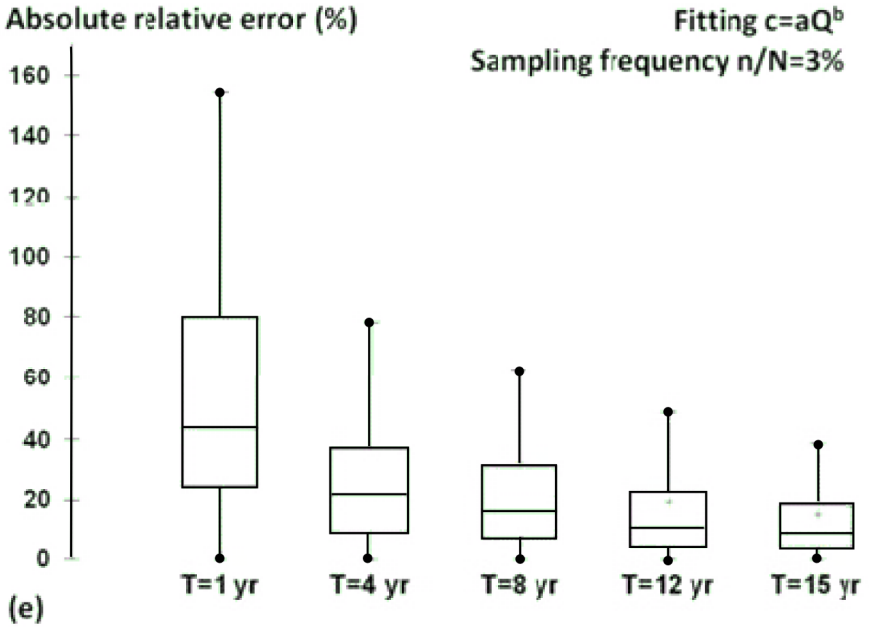
Different for rising and decreasing flow

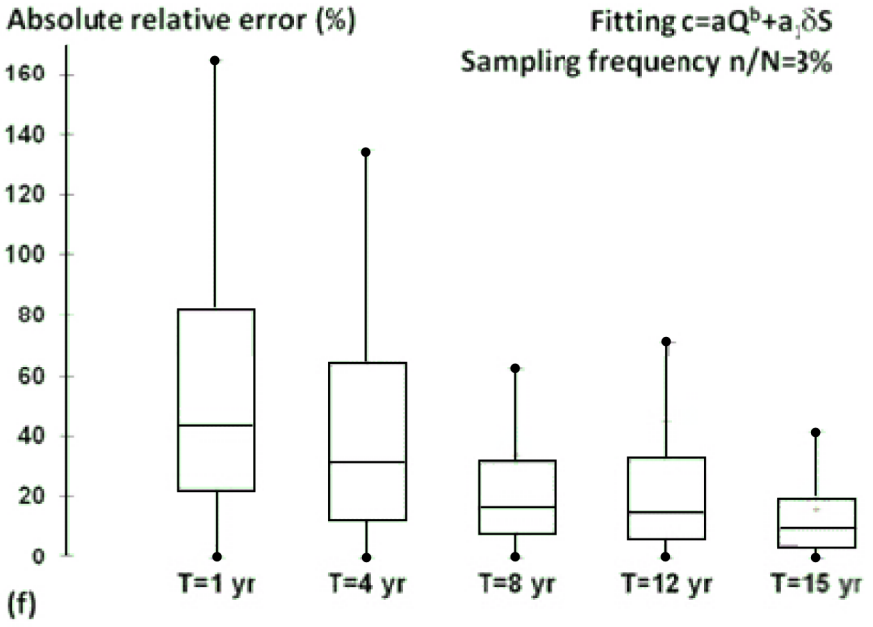
IRCA method on USGS dataset



Median value + 10% and 90% quantiles

Good news : estimation is much improved for long term evaluations



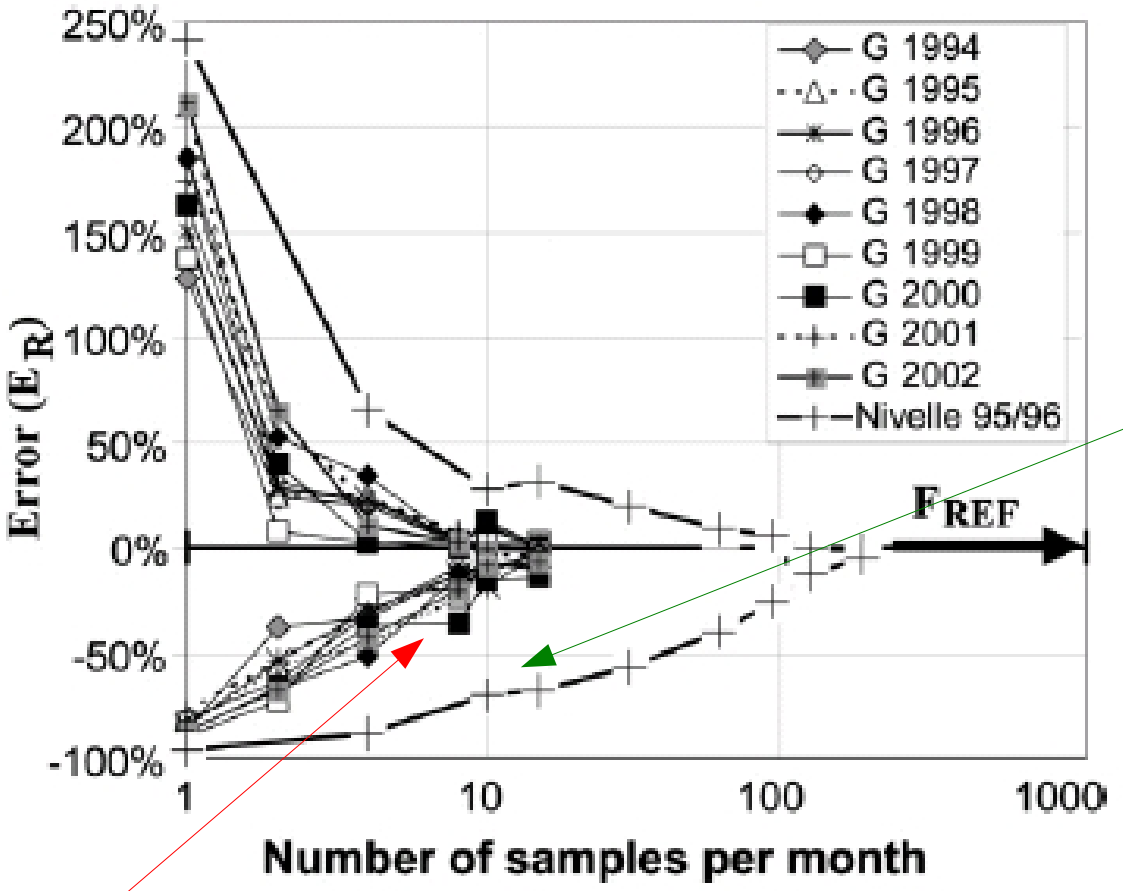


Standard rating curve

IRCA

More samples makes a better rating curve
More diverse hydrological situations
10 years, with monthly sampling => ~ 20% error

Back to the Nivelle (165 km², risky method)



But still very high for the Nivelle (small & mountainous)

Garonne, 10 samples per month 1 year => ~20% error (max)

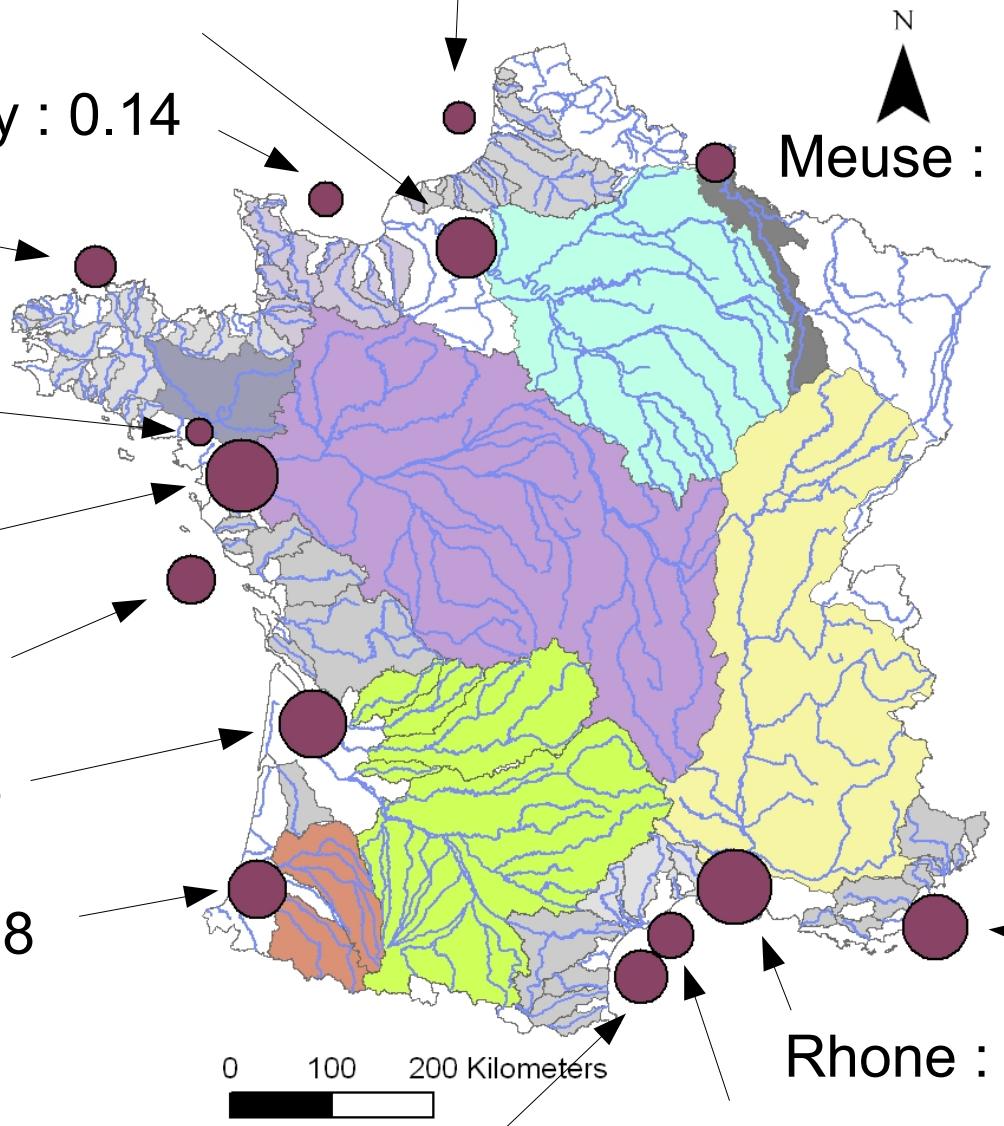
Coynel et al., 2004

Computation of sediment fluxes

- IRCA method for major rivers :
  - Seine, Vilaine, Loire, Garonne(+), Adour(+)
- 10 years of data for the Rhone river
  - Hopefully, highly problematic catchment
- Analogous catchments for small coastal streams
  - Brittany, Normandy, Northern region, Aquitaine, Cevennes, Pyrenneans, South-East
  - Same region, similar size

Channel + North sea = 7%

Fluxes (Mt/y)



Northern : 0.12

Seine : 0.8

Normandy : 0.14

Meuse : 0.15

Brittany : 0.14

Vilaine : 0.07

Loire : 3.6

Aquitaine : 0.35

Garonne(+) : 1.8

Adour(+) : 0.48

South-East : 1.8*

Rhone : 9.6

Cevennes : 0.39*

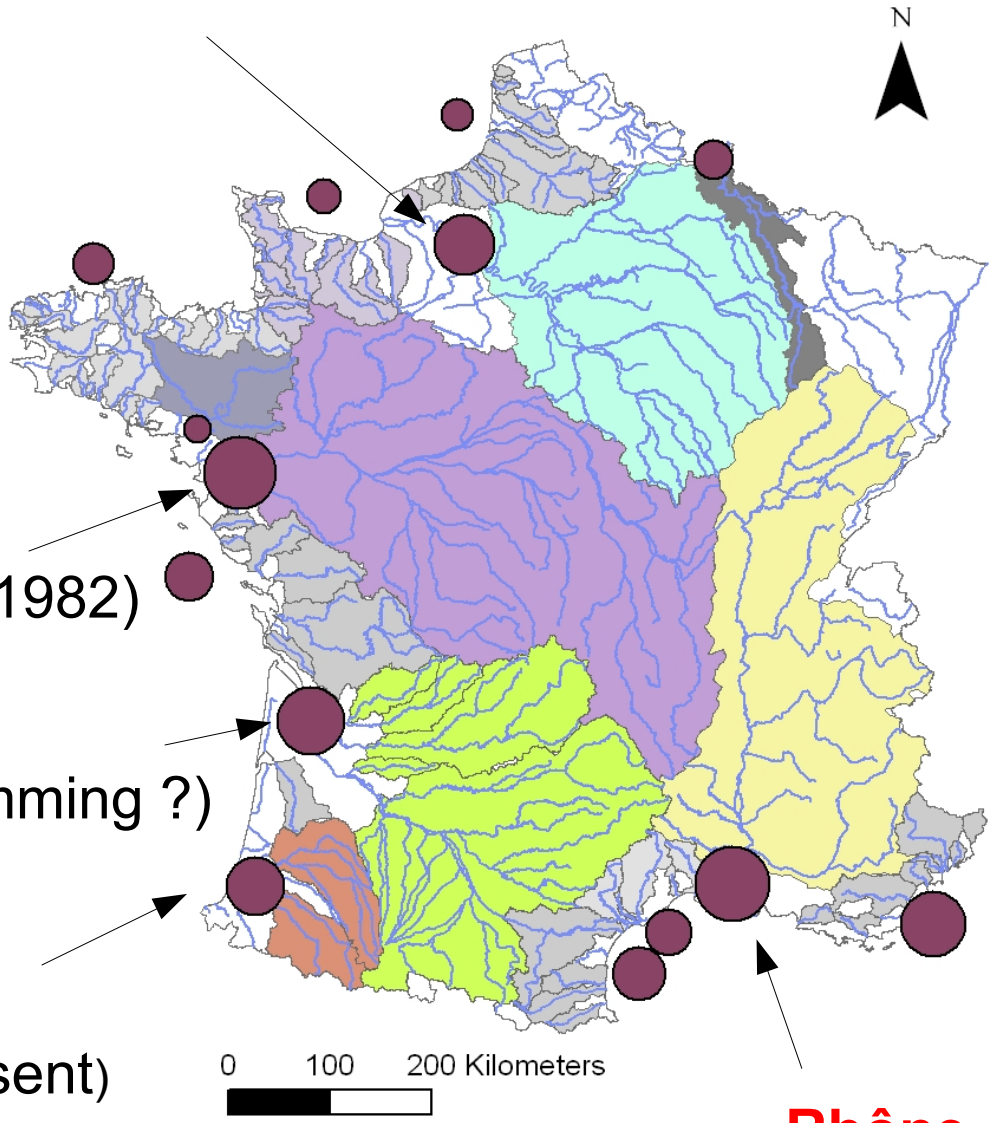
Pyrenneans : 0.38*

Atlantic = 34 %

Med Sea = 69%

*: small and mountainous

Seine
3,5 Mt/y (??)
0.7 Mt/y (present)



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Erosion rates (Hill Slope)

- Cerdan et al. 2010 (Geomorphology)
  - PESERA EU project + additional support
- Data from 81 plots in Europe (> 3m, < 200 m)
  - 2781 plot-year, 19 countries
    - Spain, Bulgaria, Hungary, Germany,...
- Database
  - Landuse (crops), slope, soil type, tillage system
- Direct extrapolation not possible
  - Plots are not representative of European soils
    - Study where problems are, and for higher slopes
- Some modelling required

Major facts

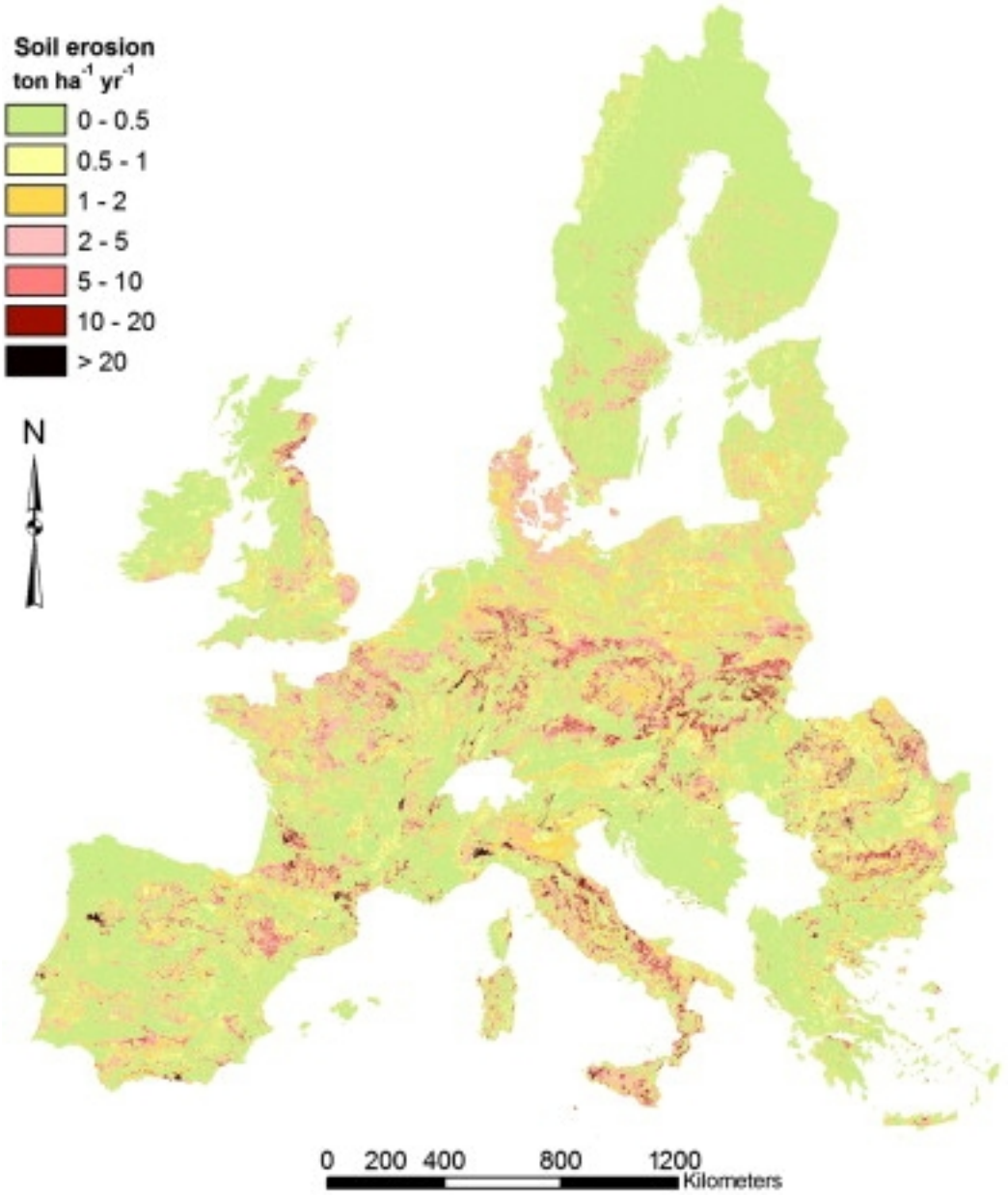
- Land use is the major explanatory factor
  - from 10-50 t/km^2/y (forest, shrub, grass) to 1500 t/km^2/y (bare soil) on average
- Vineyards, spring crops
  - 1200-1300 t/km^2/y on average
- Winter crops
  - 160 t/km^2/y
- Specific sediment yields
  - From 7 t/km^2/y (Vilaine) to 120 t/km^2/y (Rhone)

Additional factors

- Erodibility and crusting
  - From soil geographical database in Europe
  - Estimated correction factors (Le Bissonnais et al., 2005)
    - 0.1 – 5 range (mainly 0.3 - 2)
- Topography correction
  - Slope factor (Nearing, 1997)
    - 0.1 – 2 for 1% - 10% slope gradients
  - Brought to 100 m scale (0.5 power law)
- Correction for stony soils
  - -30% (e.g. Mediterranean areas)

European erosion map

(100 m scale)

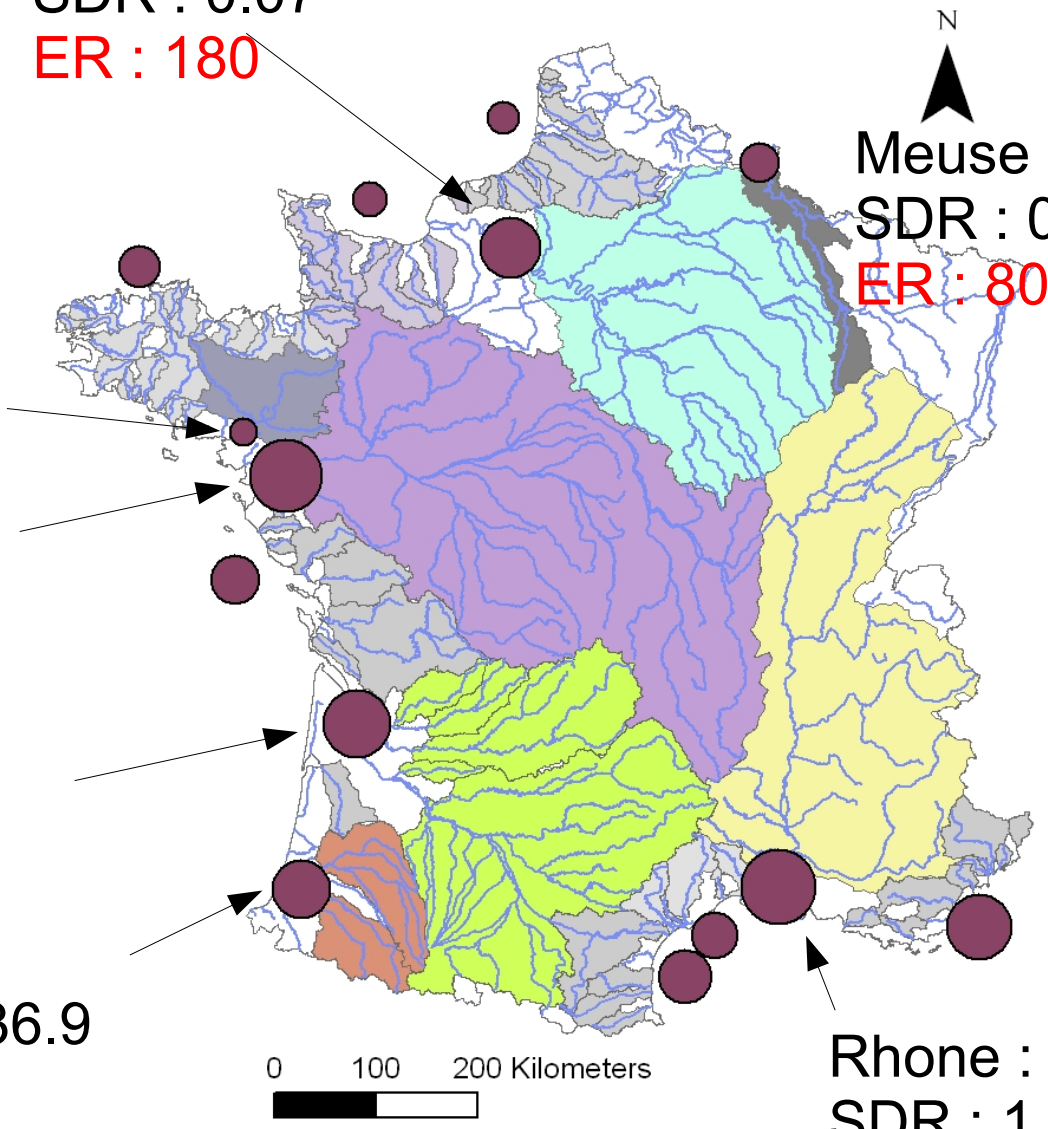


(Cerdan et al., 2010)

SSY : t/km²/y

ER : t/km²/y

Seine : 12.3
SDR : 0.07
ER : 180



Meuse : 20.8
SDR : 0.26
ER : 80

Vilaine : 7.3
SDR : 0.04
ER : 177

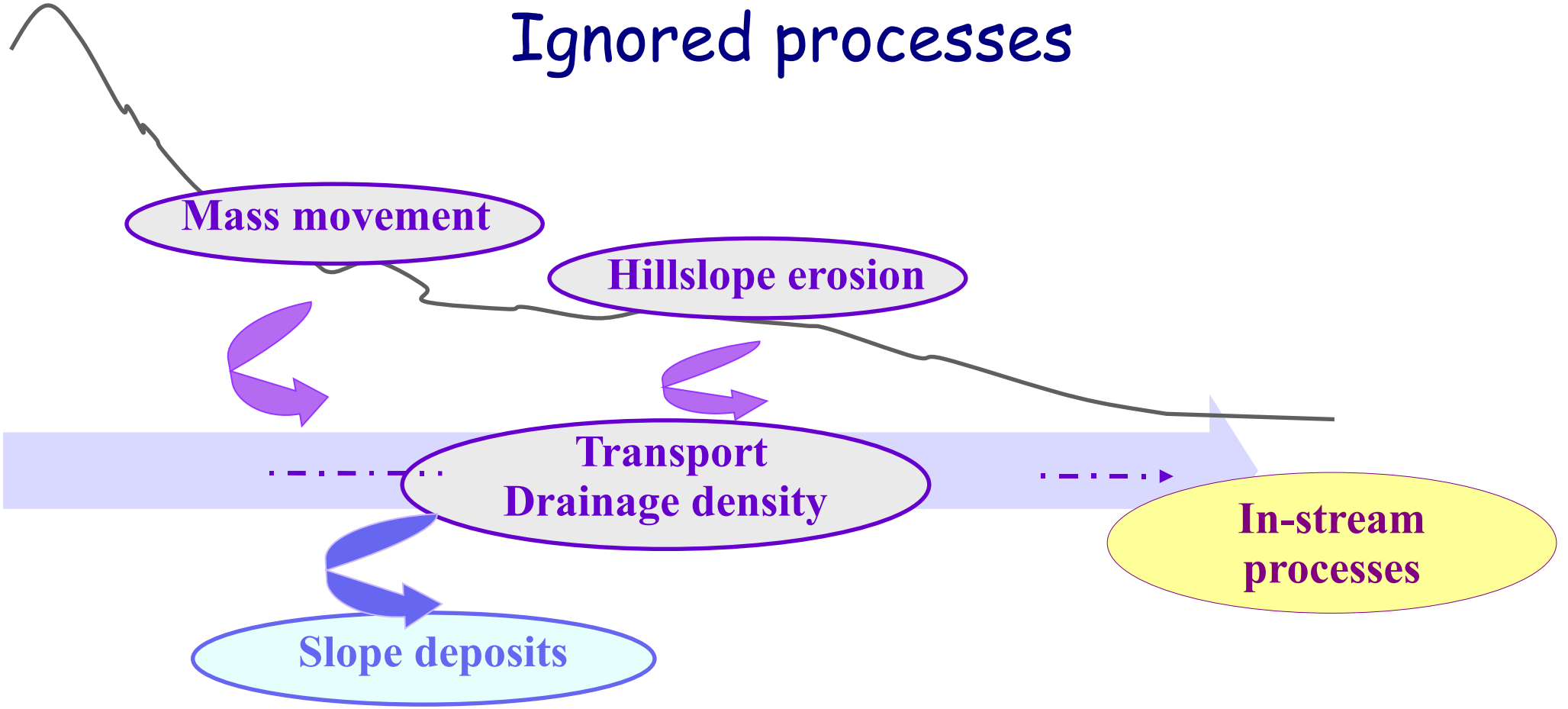
Loire : 31
SDR : 0.27
ER : 116

Garonne(+) : 26.2
SDR : 0.17
ER : 154

Adour(+) : 36.9
SDR : 0.17
ER : 212

Rhone : 115
SDR : 1.01
ER : 114

Ignored processes



A set of indicators

MM : percentage of basin area with potential mass movement from slope and geology

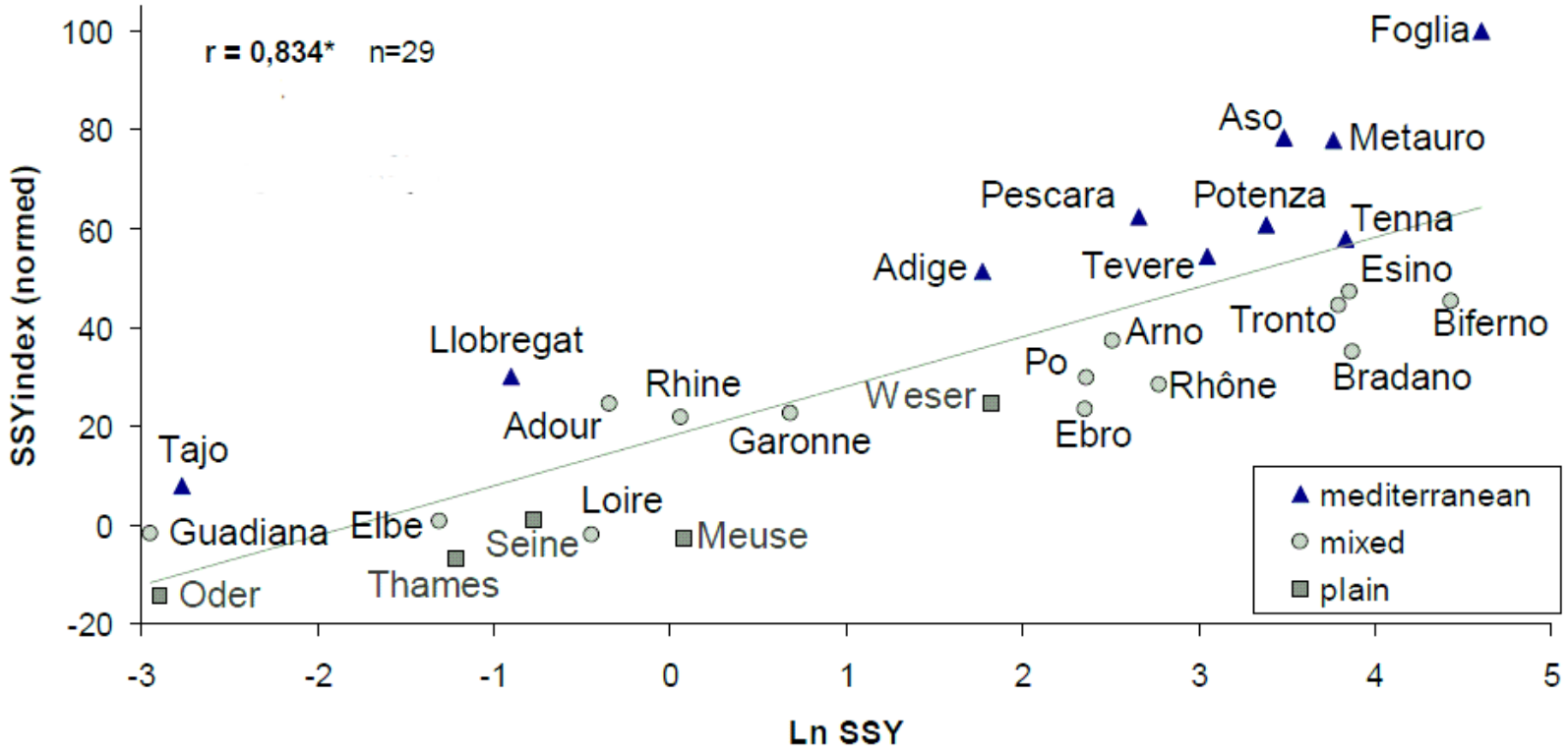
SD : percentage of basin area with slope < 2%

DD : river length to river basin area

High DD means small distance from plot to river, low infiltration and potential bank erosion

Dams not included in the analysis

Example at European scale

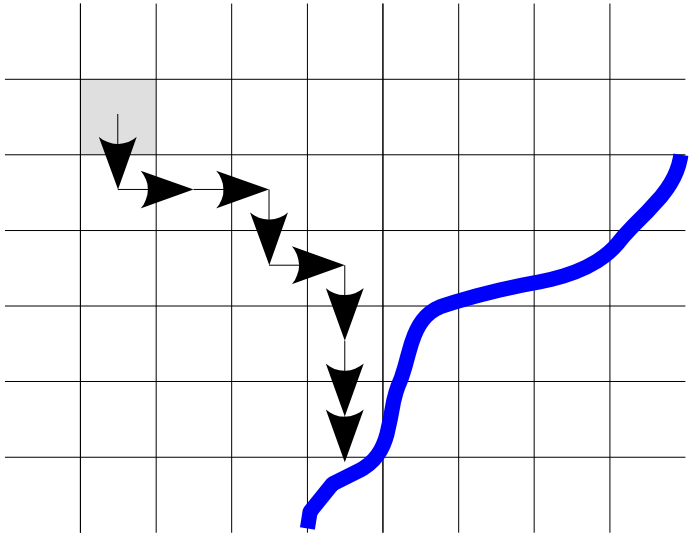


Ln(SSY) = 0.061 DD – 0.045 D + 0.034 HE + 0.047 MM – 0.8648

Everything important, but correlated (!)
MM not important everywhere (!)

Further work

- Construct a cell based model to derive cell contribution to sediment fluxes
  - Stage 1 : model the ER fraction reaching the stream starting from one cell.... on-going
  - Stage 2 : model cell to cell transport
- ... where Mass Movement can be ignored (?)
- 260 catchments available for France
  - Could certainly be expanded across Europe



Additional questions

- Is the ~20% for gentle rivers acceptable ?
  - Error estimate on flux should be improved
- Add smaller scale catchments ?
  - Higher frequency needed there, data rarely shared
- How to work with basins with significant mass movement ?
- Dare work with in-stream processes ?